A RISK BASED MODEL FOR DETERMINATION OF INHABITED BUILDING DISTANCE SITING CRITERIA

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ABSTRACT

DOD 6055.9-STD provides Inhabited Building Distance (IBD) criteria that are intended to limit personnel risk and property damage from accidental explosions. The current criteria have evolved through the observation of damage from actual explosions, from empirical studies, and from DOD policy determinations defining the interpretation of such data. The data and the decisions leading to the current standard are more than 25 years old. The current IBD standard implies a consistent risk and damage expectation. In fact, recent research, more advanced analysis, and evaluation of recent accidental explosive events have shown that the current standard provides neither consistent risk nor damage criteria. This paper summarizes the basis for the existing standard and proposes a simple model suitable for the determination of probable risk based IBD separations.

INTRODUCTION

The Department of Defense Explosives Safety Board (DDESB) and the Institute of Makers of Explosives (IME) each publish and maintain criteria that define separation distances between explosive sources and various types of receiver facilities and personnel as a function of incident overpressure. Separation distances for military explosive storage are provided in two DDESB documents, "DOD Ammunition and Explosive Safety Standards", DOD 6055.9-STD and "DOD Contractors' Safety Manual for Ammunition and Explosives", DOD 4145.26-M. Both documents utilize the same separation distances for various classes of exposure and imply the same qualitative risk.

Separation distances for commercial explosives are provided in the National Fire Protection Association (NFPA) "Explosive Materials Code", NFPA 495. The separation distances given

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in this document are taken directly from IME recommendations as given in the American Table of Distances for Storage of Explosives (ATD). Essentially all U.S. building codes directly reference either the ATD or NFPA as the source of explosive safety siting requirements.

HISTORICAL DEVELOPMENT OF DOD EXPLOSIVE SAFETY STANDARDS

The American Table of Distances for Storage of Explosives (ATD), initially published in 1910, provided the first industry guidelines for the siting of stores of explosives in the United States. The separation distances provided in the ATD were developed through a limited quantitative analysis of observed damage information obtained from previous explosive accidents. Since its initial publication, the ATD has been the source of most U.S. building code siting criteria for explosive storage.

Public safety concerns following the massive Lake Denmark accident on 10 July 1926, at what is now Picatinny Arsenal, prompted Congress to establish a formal military board to regulate the safe storage and handling of military explosives and ordnance. On 3 March 1928, this board, the forerunner of today's DDESB, recommended to Congress that the explosive safety laws of New Jersey, which were based on ATD criteria, be adapted for use by the Armed Forces. The inhabited building siting distances provided in the resulting regulations remained essentially unchanged until the end of World War II.

Observations of numerous explosive accidents during the war, ranging from small to very large quantities, indicated a wide variation in damage for the same scaled range. This led to considerable interest in more detailed evaluation of the effectiveness of the existing DOD explosive safety standards. From the end of the war until the mid-1950's, there was extensive research, analysis, and debate in the DOD over the appropriate quantity distance criteria to use. The issues of consistent risk for different types of structures, and the effectiveness of barricades in reducing overpressure at IBD were the two most controversial issues examined.

On 7 December 1956, the first quantity-distance standard for the Department of Defense (DOD 4145.17) was published. Inhabited building distances provided in this document continued to be based on ATD criteria. Unbarricaded inhabited building distances were given as twice those required for barricaded explosives, based on the perception that barricades were effective in reducing overpressure.

During the 1960's, the issue of barricade effectiveness again surfaced. There was continuing concern among members of the Armed Services Explosives Safety Board (ASESB), forerunner of the DDESB, that barricades were not as effective in reducing blast overpressure as was assumed in the ATD. In response to this concern, the Board funded an extensive study to address the effectiveness of barricades issue.

On 12 July 1966, the ASESB was presented with a detailed analysis of the effectiveness of

barricades in reducing blast overpressures at inhabited building distances. The analysis concluded (as had earlier work) that at IBD distances, a typical barricade would not provide any significant reduction in blast overpressures. Further study by the ASESB verified this conclusion. As a result, Interim change 1-5 was approved to the 1969 explosive safety document, DOD 4145.27M.

Interim change 1-5 incorporated the following revisions to ATD criteria:

- IBD of 40 W 1/3 from 50 to 10,000 pounds (barricaded explosives)
- IBD of 40 W 1/3 from 10,000 to 100,000 pounds (barricaded or unbarricaded explosives)
- IBD increasing from 40 W 1/3 to 50 W 1/3 for 100,000 to 250,000 pounds (barricaded or unbarricaded explosives)
- IBD of 50 W 1/3 for 250,000 to 500,000 pounds (barricaded of unbarricaded explosives)

This change implemented a policy decision and resulted in a significant relaxation of IBD overpressure criteria for storage of military explosives from the previously used ATD criteria. Unbarricaded IBD distances based upon overpressure for weights less than 100,000 pounds were reduced from 70 W 1/3 (twice barricaded IBD in the ATD) to 40 W 1/3 or by more than 40 percent. For weights exceeding 250,000 pounds, the new IBD required a minimum separation distance of 50 W 1/3 while the old criteria for unbarricaded explosives had required a minimum separation distance of 70 W 1/3. In addition, any consideration of variable risk for more vulnerable types of construction was eliminated.

The 1974 revision to DOD explosive safety criteria incorporated Interim Change 1-5. In addition, this revision substantially strengthened fragmentation safety requirements. Interim Change 1 to the 1974 document, issued on 26 November 1975, established 1250 feet as a "default" minimum distance for protection from both primary fragments and building debris.

Since the 1974 revision, no changes have been made to IBD distances for protection from overpressure. The "default" IBD fragmentation distance has, however, been reduced for explosive quantities of 100 pounds or less. For these quantities, the minimum IBD distance for protection from fragments is now 670 feet. For explosive quantities in excess of 100 pounds, the "default" minimum distance of 1250 feet remains in effect. As a result, minimum IBD Distances for protection from fragments will control for explosive weights up to 30,000 pounds while IBD distances for protection from overpressures will control thereafter. A comparison of current IBD distances using DOD 6055.9-STD and the ATD is provided in Figure 1.

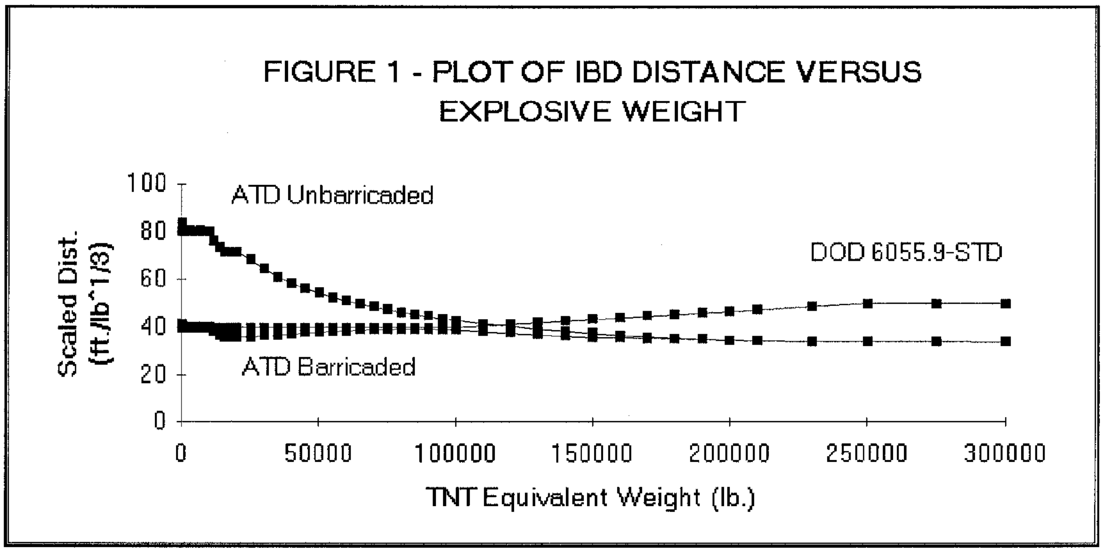

Figure 1 - Plot of IBD Distance Versus Exposive weight

RISK BASED SAFETY CRITERIA

Risk is definable in a general sense as the loss of something of value. The "value" may be human life, assets or facilities. Risk management can be defined as "knowledgeable decisions by the appropriate decision level based on risk assessment." Two elements of this definition must be considered. First, is the determination of who is the appropriate "decision maker." Secondly, in order to make knowledgeable decisions, decision makers must be provided with objective and clearly communicated risk assessments.

Accidental explosions create environmental threats to the operating facility, adjacent facilities under the control of the installation or agency, and public property beyond the installation boundary. The environmental threats are fragmentation, debris and overpressure. The DoD criteria for IBD is based on a long standing policy definition of risk, as defined in DOD 6055.9-STD. According to DOD 6055.9-STD, at IBD, "Unstrengthened buildings can be expected to sustain damage up to about 5 percent of the replacement cost . . . Personnel in buildings are provided a high degree of protection from death or serious injury, with injuries that do occur principally being caused by glass breakage and building debris."

Appropriate decision makers within the military service responsible for DoD facilities accept the stated risk and manage it through highly structured safety programs. Public facilities beyond the control of the installation represent a different situation. In this case, such facilities are not under the safety management of the military service, but they will in many

cases be separated from the explosive by the minimum IBD defined in the DoD regulation. It is not at all clear that the DoD criteria are appropriate, nor that the historical damage description used to define the DoD "risk assessment" at IBD is acceptable to the outside community.

During the 25 year period that the current DoD IBD risk criteria have been applied, numerous federal laws have been passed and implemented regarding the responsibility of hazardous material users to provide information on the potential risk to public health and safety. Agencies with regulatory duties to provide reasonable public protection from hazards include the Environmental Protection Agency (EPA), Federal Emergency Management Agency (FEMA), and the Department of Transportation (DOT). Recent Occupational Health and Safety Administration (OSHA) regulations have also required the chemical process industry to provide similar information to the public.

The thrust of the responsibilities of these regulators has been more open disclosure of threats to public health and safety. All of these agencies have the same challenge. They must be able to effectively estimate and communicate the expected risk from any given event. Over time, several methods have evolved which attempt to communicate risk for a variety of situations. These methods include:

- Ranking methods that compare relative risk of related hazards

- Risk categorizations that break down risk factors into levels

- Quantitative methods that estimate expected losses and probabilities of an event

- Comparative risk methods that relate the risk of unusual hazards to common hazards.

Whatever method is used must effectively communicate the resulting information to decision makers as well as to the public. It is fair to say that the current DoD explosive siting criteria have not been correlated with any of the risk assessment methods widely used by other governmental agencies. As DoD explosive safety management is drawn under the overall environmental risk and safety oversight of DoD, there is an increasing need to demonstrate the rationality of the quantity distance standards in a manner consistent with other widely accepted risk assessment methodologies.

QUALITATIVE EXPLOSIVE SAFETY RISK MATRIX

MIL-STD 882C establishes procedures for evaluating the risks associated with the operation of Army and DoD facilities. These procedures can be used to qualitatively evaluate the severity of an event as well as the probability of occurrence. The combination of the two in the form of a risk matrix provides decision makers with a tool to evaluate the relative risk

associated with a particular explosive source.

The procedure proposed in this paper is similar to one developed by the Huntsville Division for evaluating public risk from unexploded ordnance sites. For the purpose of this paper, the proposed model considers only determination of risk from overpressure. This assumption simplifies model development. Due to the greater distances involved, the resulting model will generally govern for public exposure beyond installation boundaries.

"Present U.S. criteria, as well as the criteria of most other nations, are based on the expectation that prescribed maximum events will occur with a probability of one. No allowance is given for the fact that some events are much less likely to happen. Decisions for criteria are made on the basis that an event will occur."[2] Based on the foregoing, the risk matrix developed in this paper assumes a conditional probability of 1.0 that an event will occur. This assumption is in accordance with current DoD safety criteria.

The proposed risk model is based on two components, hazard severity and hazard probability. A discussion of the rating system for each component follows.

Hazard Severity

For the purposes of this model as a risk management screening tool, the total quantity of explosives and the scaled range have been identified as two suitable indicators of overpressure and impulse, which control hazard severity. In the model, a point system using these indicators is employed to rate the hazard severity. Using the resulting value, the hazard severity is classified into one of four general categories. The value system used in rating the severity of the hazard was developed strictly for this paper, is subjective, and is based solely upon engineering judgement. Other more detailed value systems could be easily generated with automated analysis tools. The hazard severity rating system developed is shown in Table 1.

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[2]Chester E. Canada, Explosives Safety Criteria (Hwarangae Symposium, Korea Military Academy, 29 October 1993), p. 13.

TABLE 1 - HAZARD SEVERITY

Description	Category	Value
SIGNIFICANT	I	> 30
MODERATE	II	20 < 30
MARGINAL	III	10 < 20
NEGLIGIBLE	IV	< 10

Hazard Probability

The hazard probability addresses the likelihood and extent of exposure of the public to an explosive event. Elements that are considered in arriving at the hazard probability include (1) the type of construction, (2) the function of the facility (i.e. hospital, school, residential, etc.), and (3) the expected occupancy level. Within these three categories, values are assigned based on the potential exposure of the public to the event. Table 2 provides the proposed hazard probability rating system.

TABLE 2 - HAZARD PROBABILITY

DESCRIPTION	Level	Value
FREQUENT	A	> 45
PROBABLE	B	30 < 45
OCCASIONAL	C	15 < 30
REMOTE	D	< 15

RISK ASSESSMENT METHOD

While the hazard severity and hazard probability estimate the risk to the public, the risk assessment matrix must provide guidance to decision makers on actions or mitigation measures that should be considered. The proposed risk matrix for IBD provides a basis to define risk to the public beyond IBD from blast overpressure in a consistent methodology which can be effectively communicated to environmental managers. To demonstrate the

procedure, several types of facilities are evaluated for different potential source events. Readers should keep in mind that the evaluation procedure requires a disciplined engineering effort. The Risk Assessment Codes (RAC) proposed for this model are summarized in Table 3.

TABLE 3 - RISK MATRIX

	HAZARD PROBABILITY			
	FREQUENT	**PROBABLE**	**OCCASIONAL**	**REMOTE**
HAZARD CATEGORY	**A**	**B**	**C**	**D**
I - SIGNIFICANT	1	1	2	3
II - MODERATE	1	2	3	4
III - MARGINAL	2	3	4	5
IV - NEGLIGIBLE	3	4	5	5

RAC 1 - Potential for facility damage that would create a serious life safety risk to large numbers of building occupants. Substantial cost of facility replacement.

RAC 2 - Risk of significant facility damage that could create life threatening secondary threats to some occupants.

RAC 3 - Sufficient damage that occupancy may not be possible. Greater than 10% damage replacement cost.

RAC 4 - Facility damage in excess of 10% of value.

RAC 5 - Window breakage, minor secondary damage less than 5% of cost.

EXAMPLES OF PROCEDURE

Three different donor events, (1) 5,000 pounds TNT, (2) 200,000 pounds TNT, and (3) 1,000,000 pounds TNT are considered. Three different facility types, (1) a modern residence at 1.5 IBD, (2) a light commercial building at IBD and (3) a long span pre-engineered school auditorium at twice IBD will be evaluated. Analysis details leading to RAC's are provided in the appendix. The resulting risk matrix for each of the three donors is as follows:

FACILITY TYPE	RAC FOR EACH DONOR EVENT		
	5,000 lbs.	200,000 lbs.	1,000,000 lbs.
Residence	IV-C	III-C	II-C
Light Commercial	III-B	II-B	I-B
School	IV-A	III-A	III-A

The model presented above is intended to demonstrate a potentially viable procedure that would allow a significant improvement in the assessment of risk to the public resulting from accidental explosions on DoD installations. Policy guidance from DOD on this issue is silent or not clear at this time.

IMPLEMENTING TECHNOLOGIES

The development of severity and risk data for a wide range of facility types is within the capability of the state of the art. In the past, such efforts have been time consuming and expensive. In recent years, however, significant advances have been made in the development of computer aided engineering tools capable of providing the required data analyses. A DDESB sponsored Small Business Innovative Research (SBIR) project is underway which is expected to provide a damage prediction model which can rapidly evaluate facilities for damage. The system architecture for this model will allow it to function as a module of a larger Geographical Infomation System (GIS). The capability will soon be available to draw attributes from the GIS database, conduct analyses, and produce risk assessments with consistent results that can be communicated to decision makers and emergency planners.

CONCLUSIONS

The current DoD explosive safety standards imply a level of risk that was arrived at by a policy decision 25 years ago. The risk inherent with the current standard is neither well developed nor consistent with current methodologies. The issue of risk to the public from DoD explosive hazards should be revisited. A procedure is needed in the DoD by which public risk can be presented and evaluated. The resulting procedure should be similar to the widely accepted methods currently used in the environmental and emergency management arenas.

A possible model has been proposed in this paper which demonstrates such a procedure. Emerging automation technology, including integration of damage models with GIS, will provide the basis to rapidly apply such a model with a significant increase in the overall community ability to define and plan for risk.

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APPENDIX

Event 1 - 5,000 lbs

Event 2 - 200,000 lbs

Event 3 - 1,000,000 lbs

Facility 1 - Modern residence at 1.5 IBD

Facility 2 - Commercial construction at IBD

Facility 3 - Long span pre-engineering system at 2.0 IBD

HAZARD SEVERITY INDEX

- Hazard Severity Base Values

EXPLOSIVE LIMIT	BASE VALUE
Up to 4,000 lbs	2
4,000 - 30,000 lbs	5
30,000 - 100,000 lbs	8
100,000 - 250,000 lbs	12
250,000 - 500,000 lbs	15
Greater than 500,000 lbs	20

- Multiplication Factors (based on scaled range)

$1.0 < IBD < 1.5$	2.0
$1.5 < IBD < 2.0$	1.5
$2.0 < IBD < 3.0$	1.0
$IBD > 3.0$	0.5

NET VALUE = BASE VALUE * MULTIPLICATION FACTOR

- Hazard Severity Net Values

FACILITY NUMBER	EXPL. WEIGHT	POINT VALUE	MULT. FACTOR	HAZARD NET VALUE	SEVERITY INDEX
1	5,000	5	1.5	7.5	IV
	200,000	12	1.5	18.0	III
	1,000,000	15	1.5	22.5	II
2	5,000	5	2.0	10.0	III
	200,000	12	2.0	24.0	II
	1,000,000	15	2.0	30.0	I
3	5,000	5	1.0	5.0	IV
	200,000	12	1.0	12.0	III
	1,000,000	15	1.0	15.0	III

HAZARD PROBABILITY INDEX

CONSTRUCTION	**POINT VALUE**	**Facility 1 Value**	**Facility 2 Value**	**Facility 3 Value**
Long span pre-engineered construction	20			20
Light commercial construction	15		15	
Light residential	10	10		
Comm. const	5			
FACILITY FUNCTION				
Hospital	20			
Public Assembly/comm	15		15	15
Multi-Residential	10			
Residential	5	5		
OCCUPANCY				
High density	20			20
Moderate	10		10	
Residential	5	5		
TOTAL VALUE		20	40	55
HAZARD PROBABILITY		C	B	A